ELEMENTS OF ENGINEERING DESIGN FOR A SANITARY LANDFILL

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ELEMENTS OF ENGINEERING DESIGN

FOR A SANITARY LANDFILL

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FOREWORD

Any method of disposing of the waste products of society must be accomplished in such a way as to be environmentally acceptable. In the case of solid wastes, the final respository of choice continues to be the land, i.e., sanitary landfills. Improper design and operation can lead to environmental impairment often manifested by the release of aqueous and gaseous products of chemical and microbial attack upon the solid wastes. It can also lead to problems of unfavorable aesthetics such as blowing paper, dust, odor and general negligence. Reluctance on the part of the public to accept landfill operations is frequently in response to these conditions.

It is important to understand that a design study or proposal is developed through a stoichastic learning process which involves the designer or engineering consultant, the government official representing the regulatory body and the academic representing research interests. As a result of this interaction the quality of design work received by our office from consultants has been very good. Research proposals from the academic community as well as the consultant have also reflected this need for reciprocity.

It is the purpose of this effort to provide an overview of the engineering design elements which constitute a well planned facility as represented by acceptable current procedure. It is recognized that the field of engineering is constantly progressing with new ideas and methods coming into use. The practice of sanitary landfilling is perhaps the most vulnerable to technological development and advancement.

TABLE OF CONTENTS

Page

Introduction. 1

Section I - Planning and Design 2

1. Data Requirements 2
   - A. Hydrogeological Information
   - B. Base Map
   - C. Soil Characteristics
   - D. Solid Waste Quantities and Characteristics
   - E. Landfilling Method
   - F. Site Capacity
   - G. Cell Design and Construction
   - H. Equipment Requirements

2. Site Development Plan 11
   - A. Access road
   - B. Fencing
   - C. Buffer zones and screening
   - D. Utilities
   - E. Drainage facilities and erosion control
   - F. Special Waste Facilities

3. Phased Development Drawings 15

Section II - Operations Plan. 17

Section III - Costs 19

Section IV - Groundwater Protection Design. 24

1 Leachate Generation and Contaminant Migration 24

2. Leachate Movement and Control 25

3. Leachate Collection 29

4. Leachate Treatment. 30

5. Leachate Recycle and Irrigation 31

Section V - Gas Generation and Control. 33

Section VI - Monitoring Plan and Post Closure Responsibility. 35

Section VII - Final Land Use Plan 49

Section VIII - Operations Management. 51

Reference List. 52

INTRODUCTION

After all the piezometers and observation wells have been installed and the soils, geologic, and groundwater characteristics have been analyzed we now have the necessary scientific data to proceed with the engineering design of the landfill.

The design program considers two important factors:

a) Economics

b) Environmental Impact.

Therefore, all design parameters are based on the available landfill development space which strives to optimize these factors.

SECTION I PLANNING AND DESIGN

1. DATA REQUIREMENTS

A. HYDROGEOLOGICAL INFORMATION

Existing field reports which assess the hydrogeological environment of the site are reviewed. These are in the form of preliminary investigations for the purpose of establishing site suitability with respect to certain site selection criteria. After the designer has reviewed this information, very often he will request further field testing to provide him with a more detailed, composite evaluation. In the case of our department's waste management program, the Soils Branch would conduct this evaluation. In the case of city facilities, this work is contracted to a consulting firm, very often the same firm that is doing the design work.

B. BASE MAP

A base topographical map of the site usually at a scale of 25 m to the cm with 1.5 m intervals is prepared. These maps should show the following information:

a) the proposed site area and the boundaries

b) access to the site

c) existing services

d) zoning and surrounding land use

e) surface drainage

f) borrow pit and fill areas

g) locations of all residences, buildings, transmission lines, underground and surface mines, oil and gas wells and other applicable details which may serve to limit the normal operation of the landfill within 500 m of the site boundaries.

C. SOIL CHARACTERISTICS

Plans, profiles, reports describing the characteristics and areal extent of soil material on the site are prepared.

It is important to maximize the use of onsite earth materials as a cover source. Cover material should be suitable soil or other material of such character that it compacts well, does not crack excessively when dry and is relatively free of decomposable materials and large objects.

Where cover material is limited in quantity or is not available on the site, design and operational plans must include a description of source of cover material, indicating such things as soil types, volumes to be used, transport methods, and contract arrangements. Approximately $1m^3$ of cover material will be required for every $4\text{-}6m^3$ of solid wastes.*

A final cover of 0.6 m (2 ft.) must be placed over all areas that have been landfilled. Over this, it is recommended that a 15 cm (6 in.) cover of topsoil be placed on the entire area to reclaim it to a condition which would sustain a vegetative growth

Because of the wide variations possible in texture, soils offer a wide choice of materials of differing porosity for gas and water

* The Provincial Board of Health requirement is 150 mm cover material for each cell completed. The ratio used is for a cell height of 0.6 m - 1 m. The cell volume however, will vary from operation to operation.

movement or containment. Soil for cover on waste must be manipulated in many ways to function effectively, for example:

a) Land management and usage
   - minimize settlement and maximize compaction
   - fertilize for vegetation growth
   - minimize erosion
   - preserve slope stability
   - control water movement

b) Health values
   - minimize vector breeding
   - maximize insect control
   - control water infiltration
   - control harmful gas migration
   - minimize potential fire hazard

c) Aesthetic values
   - provide a base for vegetation of desirable appearance.
   - control odors
   - control paper and trash blowing.

Thus soil covers may function in ways that are conflicting or complementary. A list of functions in order of priority, therefore, must be established in the selection of soil material for its placement and manipulation over waste.

E. SOLID WASTE QUANTITIES AND CHARACTERISTICS

Waste generation data from existing regional systems within the province is sketchy at this time because of their short time in operation. We will be reviewing these data to determine waste

generation rates for the various regional systems. This information is necessary in determining site capacity.

Studies conducted in other parts of the country indicated that municipal solid waste is being generated at a rate between 1-2 kg per capita per day (2.2-4.4 lbs.). This includes the normal mix of residential, commercial, and institutional waste that is produced through a regular collection procedure. Excluded from this rate are waste items such as building construction debris, discarded furniture, and other bulky wastes. These wastes are stockpiled within specific areas within the landfill site. Based on these generation rates, a conservative estimate of 0.75 tonne (0.83 ton) per capita per year can and is usually used for assessing the life expectancy of the site. For design purposes, it is assumed that this rate does not increase with time but is adjusted with population growth. Population growth figures can be obtained from the regional planning authority.

Waste quantities can be estimated by using weigh scales or by reviewing each load as it enters the site. The latter method requires knowledge of weights carried by various types of vehicles and very close supervision.

Almost any type of residual material can be delivered to a sanitary landfill. However, the waste type most commonly encountered is generated by residential and commercial sources and consists of a mixture of paper, wood, metal, glass, food wastes, yard trimmings, plastics, rubber, oil, and other material. Industrial wastes of many types are also received unless the site is to be closed to these materials. Sludges, liquids, and hazardous chemicals may be expected if alternative disposal methods are unavailable and if their disposal at

the landfill is permitted by the local regulatory agencies. Other hard-to-handle bulky materials, such as auto bodies, refrigerators, and demolition debris, can also be expected unless specifically excluded. Solid waste may be delivered in baled form or may be shredded prior to disposal on land. The physical condition of the waste, whether it is processed or unprocessed, will influence the methods and equipment used in filling operations.

E. LANDFILLING METHOD

The designer of a sanitary landfill must prescribe the procedures to be followed in disposing of solid waste. The specific method of filling will depend on the characteristics of the site, such as topography, the amount of available cover material, hydrogeological conditions and the amount and types of solid wastes to be handled.

The two basic landfilling methods are trench and area; other approaches are only modifications. In general, the trench method is used when the ground water is low and the soil is more than 2 m deep. It is best employed on flat or gently rolling land. The area method can be followed on most topographies and is often used if large quantities of solid waste must be disposed of. At many sites a combination of the two methods is planned.

On the basis of characteristics of the site or the method of operation it may be necessary to incorporate special features for the control of the movement of gases and leachate from the landfill.

F. SITE CAPACITY

Once a filling plan is selected, it is possible to calculate site capacity. The expected daily, yearly, and cumulative yearly total waste

quantities are tabulated. The daily and yearly waste quantities are computed on the basis of projected end-of-year population. The volume is then computed assuming a value for the in place compacted density of the solid wastes. This value is dependent on the type of machine used for compaction. For example a crawler machine of 977 size or equivalent can achieve a compaction density of 420 kg/m^3 (700 lb/yd^3). The computed values can be scaled for any other assumed density values.

The volumetic capacity of the landfill site is then computed given the useable area and the lift height or excavation depth. The volume of solid wastes is determined by multiplying the total volume by 0.8 on the assumption that 1 m^3 of cover material will be required for every 4 m^3 of solid waste.* By referring to the cumulative total volume. the life expectancy of the site is then given.

The capacity of the trench-type landfill is therefore controlled by depth of excavation, maximum height of fill, ratio of refuse to daily cover, compacted density of solid wastes and efficiency of operation. In a balanced design where there is no excess or imported materials, all of these factors are closely related.

The following guidelines affect capacity of a site:

a) the maximum depth of excavation should be controlled by the danger of groundwater pollution. Economic considerations become important when groundwater problems are not evident.

b) The maximum acceptable average height of refuse above land is dependent on the final land use proposed.

* The multiplier will vary depending on the ratio of cover material to refuse quantities.

G. CELL DESIGN AND CONSTRUCTION

The building block common to both the trench and area methods of fill is the cell. All the solid waste received is spread and compacted in layers within a confined area. The Provincial regulations for design and operating standards require that spreading and compacting be done in layers of 0.6 m (2 ft.) maximum.

As the construction of the cell is completed during the day, a minimum of 150 mm (6 in.) of compacted soil cover should be placed so that only a minimum part of the working face remains to be covered at closing time. The compacted waste and soil cover constitute a cell. A series of adjoining cells, all of the same height, makes up a lift. A minimum thickness of 0.3 m (1 ft.) of compacted intermediate cover should be placed on operating areas that will not be used again for an extended period of time. The completed fill would therefore consist of a one or more lifts.

The dimensions of the cell are determined by the volume of the compacted waste, and this in turn depends on the density of the in-place solid waste. No hard-and-fast rule can be laid down regarding the proper height of a cell. Some designers think it should be 2 m (8 ft.) or less, presumably because this height will not cause severe settlement problems. On the other hand, if a multiple lift operation is involved and all the cells are built to the same height, whether 2 m or 4 m, total settlement should not differ significantly. If land and cover material are readily available, a 2 m height restriction might be appropriate but heights up to 10 m are common in large operations. Rather than deciding on an arbitrary figure, the designer should attempt

to keep cover material volume at a minimum while adequately disposing of as much waste as possible.

Cover material volume requirements are dependent on the surface area of waste to be covered and the thickness of soils needed to perform its particular function. As might be expected, cell configuration can greatly affect the volume of cover material needed. The surface area to be covered should, therefore, be kept minimal.

In general, the cell should be about square, and its sides should be sloped as steeply as practical operation will permit. Side slopes of 20° - 30° (3:1, 2:1) will not only keep the surface area, and hence the cover material volume at a minimum, but will also aid in obtaining good compaction of solid waste.

Provisions to vent methane and other landfill gases must be provided as required.

H. EQUIPMENT REQUIREMENTS

The site designer must plan for sufficient equipment capability to adequately spread, compact, and cover all solid wastes delivered by each day's end.

There are two important points that must be stressed. The equipment must be reliable and it must be of the minimum size necessary for proper compaction and other tasks. Since an occasional breakdown is inevitable even with the most reliable equipment, there should be sufficient additional equipment at the site or arrangements for standby units to be brought into the site at any time.

In selecting the proper equipment, consideration must be given to the following:

a) quantity and type of refuse

b) quantiy of soil to be moved

c) type of soil

d) distance soil must be moved

e) time required for covering and soil compaction

f) site clearing requirements

g) site conditions and soil conditions such as topography, soil moisture, and difficulty in excavation

h) auxillary tasks such as maintaining roads and drainage, assisting in vehicle unloading, and moving other materials and equipment around the site

i) maintenance needs

j) standby or backup equipment needs

k) growth of refuse quantities and related tasks over the life of the equipment

l) lower reliability with age

m) variation in refuse quantities received

n) variation in weather conditions

o) availability of parts and maintenance

p) purchase and operating costs

q) operator comfort

Each of these points refers to a time requirement or a certain capability. Equipment sizes, numbers, and types must be selected to handle these conditions, or arrangements must be made for other equipment to be brought in to temporarily assist. With the many factors involved, it is absolutely necessary that the equipment never be undersized.

The reliability of the equipment will depend on the frequency of routine preventive maintenance and the care taken in operating the equipment. It is the responsiblity of the site foreman (who may also be the operator) to see to proper maintenance and careful use of the equipment. A dated listing or chart of the routine maintenance performed should be kept. Much of the information or maintenance can be obtained from the manufacturer's literature.

2. SITE DEVELOPMENT PLAN

A sanitary landfill may be likened to a long term construction project. Most aspects of conventional construction activity are undertaken including clearing, earthwork, road construction, building design and erection, drainage control, and installation of utilities. In addition special attention must be given to the design of features unique to a sanitary landfill operation. These include provisions for litter control, gas and leachate control, subsidence and differential settlement control, construction of temporary facilities, phased construction of solid waste cells, final grading of the site following cessation of filling activity, and landscaping. The following elements should be addressed.

A. ACCESS ROAD

An all weather access road must be provided from the municipal road to the site. This road should be designed to safely accommodate the anticipated volume of vehicular traffic and should be maintained at 5% grade or less and its intersection with the existing public road should be carefully designed to reflect traffic volumes and safety

requirements. These considerations should be cleared with the local highway authority.

The width of road varies but should generally not be less than about 7 m (24 ft.). A 25 m on-site right-of-way would provide the sufficient width to construct a rural road cross-section with ditches and space to install services for the operation.

The access road will generally terminate at the scale or other delivery control facility. Temporary roads that are utilized for transporting wastes from this point to the unloading area may be constructed of on-site soil with a topping of suitable material such as pit-run gravel, broken concrete or asphalt or demolition wastes. Lime, portland cement, or asphalt may be used as binders to maintain stability of the roads and to control dust. Plans should include provisions to keep the access road and adjacent public roads free of mud and litter.

As on-site roads are constructed over previously filled trenches, maintenance of these on-site roads will increase somewhat because of settlements that will occur.

B. FENCING

Fencing is used to control or limit access to the sanitary landfill and to control littering from blowing wastes. Permanant or portable, or both, woven and chain link fencing is commonly used for these purposes. A gate should be provided at the site entrance and should be closed and locked when the site is unattended or otherwise closed to users. The entrance should be attractively designed and landscaped. A sign prominently located should identify the sanitary landfill site, the hours of operation, fees and any restrictions on users or materials

acceptable for delivery. It may be beneficial to provide drop-box containers at the landfill entrance gate for wastes delivered after hours. This system, however, may become abused, resulting in littering.

C. BUFFER ZONES AND SCREENING

Buffer zones adjacent to the site boundaries serve a number of purposes:

a) to a certain degree, the buffers safeguard adjacent properties from escaping litter.

b) provide an undisturbed area where observation wells can be placed for monitoring groundwater conditions during the operation of the site.

c) provide a temporary storage area for excess soil.

d) insure that the final contour from all fill areas to the property line can be completed on reasonable grade.

e) trees and shrubs may be planted within the buffer zones or existing tree cover can remain to act as a screen which would improve the overall site aesthetics.

D. BUILDINGS

Equipment used at the site should be provided with a shelter. A single building or shed may be used both for equipment maintenance and storage, as well as for office purposes. Appropriate sanitary facilities must be supplied for sanitary landfill employees and users of the site. Portable chemical toilets can be used for this purpose. At larger sites, employees should be provided with shower and lunchroom facilities. Generally the design of such facilities will depend upon the size and planned duration of landfill use.

E. UTILITIES

Ideally, each sanitary landfill should be provided with power, water, and telephone. Water in sufficient quantities and under adequate pressure is needed in the event of a fire, for machine maintenance, and for dust control. Potable water should be made available for site personnel. A telephone or radio should be provided for communiciations. Communiciations are particularily important in the event of an accident or a fire at the landfill.

F. DRAINAGE FACILITIES AND EROSION CONTROL

Appropriate permanent and temporary drainage facilities must be provided to control surface runoff at the site. Surface waters must be diverted away from the areas to be filled with solid waste. Open channels are commonly used for this purpose. Depending on expected flow rates, the channels can be of earth, lined with asphalt or rubble, or may be constructed from half sections of concrete or corrugated metal pipe.

The completed surface of the landfill should be maintained at a slope of not less than 2% to insure that precipitation incident on the surface will run off to the drainage facilities. Side slopes should not exceed 2 to 1. Flatter side slopes may be required depending on rainfall quantities, soil characteristics, and other factors such as surface vegetation.

The surface of the landfill can be expected to subside from 5% - 20% of the landfill depth. The occurrence of surface cracks and depressions due to settlement can be minimized if 0.6 - 1.2 lm (2 - 4 ft.) of final cover is applied and periodic grading is performed. Site

development and final use plans must provide for filling in of surface depressions to prevent ponding of water. Appropriate means of erosion control must be provided.

G. SPECIAL WASTE FACILITIES

Many types of solid or semisolid wastes are delivered to sanitary landfill sites. Most wastes can be received, unloaded and disposed of in a conventional manner. However, there are certain wastes that, because of their physical and chemical nature require special handling and/or storage. Examples of this waste may include:

a) processed sludge, used oil

b) bulky, powdery and low density wastes such as demolition debris, automobiles, appliances, rubber tires, brush and dry chemicals.

c) dead animals.

The landfill design should allow for storage and/or disposal away from the normal refuse. Co-disposal of these items is a poor waste management practise in terms of groundwater protecton, space efficiency or working face handling.

3. PHASED DEVELOPMENT DRAWINGS

A series of drawings is prepared, using the base topographic map as a starting point. The entire series presents a phased development plan for the site and is composed of the following:

a) Base map showing existing topography with initial site improvements.

b) Several interim maps or cross sections, or both, depicting the site topography, excavation and improvements at various stages of site completion. Interim grading plans should be somewhat flexible to allow for revisions due to changing field conditions.

c) Detailed drawings showing typical cells, lifts and roads, as well as gas and leachate controls, where used.

d) A final map illustrating planned contours and minimum surface slopes when the landfill is completed. This map may also illustrate the planned use and facilities to be located on the completed landfill.

The number of interim drawings will depend upon the size of the landfill and the rate at which the site is filled. The filling activity should be shown at staged intervals adequate to properly guide site operators and maintain efficient site use. The interim maps should illustrate areas to be filled with waste, areas where cover material is to be excavated, newly constructed temporary roads, and drainage facilities for each stage.

Appropriate survey control should be established to provide reference points for measuring the progress of the filling activity and for settlement monitoring.

SECTION II - OPERATIONS PLAN

The best possible design of an engineering structure or process is of little value unless it is constructed and operated accordingly. The daily operation of constructing the sanitary landfill according to the design should be clearly prescribed. An operational procedures manual should be provided to assist the operators in the implementation of the site design and operational specifications. Our department is in the midst of preparing a general operators manual and offering it during a two to three day operators seminar. Very briefly, operation design features are outlined herein.

a) working face practises

b) personnel motivation and training

c) selection of proper equipment

d) choosing optimal operation hours

e) on-site road maintenance planning

f) method of operation

g) inclement weather operation

h) on-site communication

i) control practices

- dust control
- litter control
- fire control
- erosion control

j) equipment maintenance

k) operational records

l) waste measurements

m) safety

n) special waste facilities

o) field engineering

p) public relations

SECTION III - COSTS

The costs associated with the sanitary landfill are divided into capital costs and operating costs.

Capital cost items are considered as one-time cost expenditures which are normally amortized over the life of the facility. However, current inflation rates indicate that a more realistic approach towards depreciating the capital costs is to institute a depreciation reserve fund for all capital costs, other than the equipment expenditures which terminate earlier than the site life period. The capital costs for mobile equipment generally are depreciated over the expected life of the equipment. Both these depreciation methods are considered to be adequate in establishing a reserve holding fund which can be used in future years for the replacement of facilities and equipment.

Reclamation costs can be considered as being above and beyond both normal capital improvements and operational costs. A separate reclamation fund should therefore be established to insure that the site can be reclaimed for general agricultural use or for recreational use when required in the development plan.

The following is a summary of operating and capital costs for five regional sanitary landfill operations:

PINCHER CREEK REGIONAL LANDFILL

Capital costs (1977):

1. Site Preparaton	$ 33,000
2. On-site access road	9,400
3. Building	47,000
4. Fence, gate, signs	37,000
5. Weigh scales	15,000
6. Utilities	9,500
7. Waste Oil tanks (2)	3,400
8. After-hours waste container	2,700
9. Miscellaneous tools and equipment	8,400
10. Compactor	68,000
11. Loader	66,000
12. Half-ton truck	6,100
13. Off-site access road	115,000
	$420,500

Pincher Creek Regional Landfill Operating Costs (1979):

1. Manpower on spreading, compacting covering and weighing	$ 54,600
2. Equipment operating and maintenance	14,000
3. Utilities	5,700
4. Administration	3,500
5. Reserve find	33,000
	$110,900
LESS REVENUE -	11,400
	$ 99,500

Population: 14,400
Per Capita: $6.90

DRUMHELLER AND DISTRICT

1980 Budget

	HAULAGE	LANDFILL
Population Served	15,809	22,973
Annual Per Capita Cost (plus $0.50 membership fee)	$4.72	$2.05

LEDUC REGIONAL LANDFILL

Capital Costs:

1.	Site Preparation - topsoil stripping - trench excavation	$ 35,000
2.	On-site access road	38,000
3.	Building	55,000
4.	Fence, gate, signs	37,300
5.	Weigh scales	15,000
6.	Utilities	17,500
7.	Waste oil tank	7,000
8.	Engineering	35,000
9.	Miscellaneous	20,000
10.	Off-site access road	111,000
11.	Compactor	143,000
		513,800

Operating Costs:

1.	Spreading, compacting covering - including operator	$ 67,000
2.	Hauling and trenching including operator	15,000
3.	Weighing - including attendent	14,000
4.	Utilities and Maintenance	3,000
5.	Administration	5,000
		$104,000

Acres: 88
Population: 13,000
Per Capita: $8.00

Leduc: 1979 Operation Costs (March - December)

1.	Labour and equipment (on contract)	$ 68,672
2.	Supplies	389
3.	Utilities	453
4.	Miscellaneous Services	1,087
5.	Administration	8,250
		78,851
	LESS DUMPING CHARGES -	2,175
		$ 76,676

1979 Population: 17,000
Per Capita: $4.50

STURGEON REGIONAL LANDFILL

Capital Costs:

1.	Site Preparation - topsoil stripping - trench excavation	$ 82,000
2.	On-site access road	39,000
3.	Building	167,000
4.	Fence, gate, trees	37,500
5.	Weigh scales	15,000
6.	Utilities	9,500
7.	Waste oil tank	7,000
8.	Crawler Dozer	100,000
9.	12 cu. yd. scraper	25,000
10.	Sings, monitoring, misc.	15,000
11.	Off-site access road	51,000
12.	Leachate collection	150,000
		$698,000

Operating Costs:

1.	Spreading, compacting covering - including operator	$ 41,500
2.	Hauling and trenching including operator	51,500
3.	Weighing - including attendant	20,000
4.	Utilities and Maintenance	5,000
5.	Administration	8,000
		$126,000

Acres: 120
Population: 22,400
Per Capita: $5.20

FLAGSTAFF REGIONAL LANDFILL

Capital Costs:

1.	Site Preparation - topsoil stripping - trench excavation	$ 18,000
2.	On-site access road	8,000
3.	Building	43,000
4.	Fence and gate	22,000
5.	Weigh Scales	17,500
6.	Utilities	22,100
7.	Crawler Dozer	140,000
8.	3/4 ton truck	8,000
9.	Monitoring and Misc.	8,300
		$286,900

Operating Costs:	
1. Operator	$ 14,000
2. Attendant	12,000
3. Equipment Operating	6,760
4. Equipment Maintenance	8,000
5. Utilities and Administration	10,500
6. Maintenance	3,500
7. ReplacementFund	34,076
	$ 88,836

Acres: 70
Population: 10,000
Per Capita: $8.64

SECTION IV - GROUNDWATER PROTECTON DESIGN

It is a basic premise that groundwater and the deposited solid waste not be allowed to interact. It is unwise to assume that a leachate will be diluted in groundwater. Very little mixing occurs in the aquifer because the groundwater flow there is usually laminar. Mineral pollutants can travel long distances through soil or rock formations. In addition to other considerations, the designer must evaluate:

a) the amount and projected use of the water resources of the area

b) the effect of leachate on groundwater quality

c) the direction of groundwater movement

d) the interrelationship of this aquifer with other aquifers and surface water.

1. LEACHATE GENERATION AND CONTAMINANT MIGRATION

Contaminants can be leached from buried garbage by several mechanisms including:

a) downward movement of surface water into buried garbage

b) mixing of liquid and solid wastes

C) contact of buried waste with the water table

In the first two instances, leachate generation can be either eliminated or reduced to negligible quantities by elimination of a surface source of water. Waste buried in well drained areas above the water table does not produce significant quantities of leachate in Alberta because of the low rates of precipitation over most of the province. The third instance has been the source of considerable controversy. It is commonly held that garbage must be buried above the

water table in order to avoid contaminating groundwater. While this is the case, it is commonly difficult to locate sites in populated areas of the province where the water table lies at a depth sufficient to allow for excavation of deep trenches. For this reason, landfilling of municipal waste below the water table should be considered in areas where it can be demonstrated that adverse impact to the groundwater system will not occur; however, these designs generally require expensive leachate collection/treatment systems.

Little work has been done to determine the types and costs of leachate treatment. Analysis of leachate samples from a few landfills and laboratory lysimeters indicates that leachate is a complex liquid waste and has variable characteristics. Since most of the contaminants in leachate are water soluble, conventional biological and chemical treatment methods are being studied, and hopefully will prove effective.

2. LEACHATE MOVEMENT AND CONTROL

Under normal conditions, leachate is found in the bottom of landfills. From there its movement is in the underlying strata, although some lateral movement may also occur, depending on the characteristics of the surrounding material.

As leachate percolates through the underlying strata, many of the chemical and biological constituents originally contained in it will be removed by the filtering and adsorption action of the material composing the strata. In general, the extent of this action depends on the characteristics of the soil, especially the clay content. Knowledge of interactions between contaminants and soil is continually increasing. It is necessary to understand the way biological, chemical and physical

characteristics of the soil and geologic materials interact with wastes. The soil can be regarded as a waste treatment/utilization system. The identification and measurement of those component parameters that influence constituent retention in soils is essential to effective disposal management practises. Specifically, the following areas may be addressed in a curriculum of research activity:

a) develop models for prediction of migration rates for pollutants and generate quantitative data on factors affecting migration through soil

b) determine the alteration capability of a variety of geologic materials for a specific leachate quality

c) study the complexation characteristics of leachate and determine the role played in migration. The rate and extent of alteration of heavy metals can be affected by the extent to which soluble complexes are formed between the metals and other components of the leachate.

d) study the physical, chemical and biological characteristics of the soil and determine quantitatively the effects on migration rates.

Because of the potential risk involved in allowing leachate to percolate to the groundwater, best practice calls for its elimination or containment. Among the methods of leachate control are:

a) interception of upland drainage.

b) use of relatively impermeable soils for cover material

c) compacting, grading and sloping of the daily and final cover to allow runoff

d) planting of high transpiring vegetation

e) use of impermeable membranes overlying the final lift of solid waste

f) use of subsurface drains and ditches to control ground water

g) use of an impermeable liner (natural or synthetic) to prevent the movement of leachate into the ground.

Special situations can be met by collecting, treating and disposing of leachate. Compacted clay or man-made materials may be used as liners on the bottom and sides of the area to be filled. Collector drain lines and sumps may be placed for collection of leachate.

All soil materials that fulfill containment functions may be considered liners. Some liners must be impermeable to water and associated contaminants and must maintain a structural integrity until the waste has stabilized and the potential for leachate generation has fallen to safe limits. The usefulness of a soil liner depends upon the nature of the liner material as it may interact with the environment in which it is expected to operate.

One of the oldest materials used as a sealant is bentonite clay. Having a montmorillonite type of expanding lattice structure, this clay expands and contracts upon wetting and drying. Leaks appear more frequently with this type of clay, under wetting and drying conditions, than when nonexpanding lattice clays such as kaolinite and illite are used. Imported bentonite clay thick enough to prevent water movement through closed dipsoal site is very expensive and is often mixed with the native material.

Studies have shown that bentonite mixed with fine sand at a ratio of 1:20 can be used to produce permeabilities in the order of 10^{-8}an/sec. However, there is evidence that bentonite reacts chemically with leachate and looses some of its swelling properties. Non-swelling, relatively pure illite-type clay may be considered as an alternative to bentonite.

Native fine-textured soils (at least 20% clay and 15 meg/100 gm CEC) may be compacted as a liner. Lining depth will vary with the clay content of the soil.

Soil is also used along with other types of liners for

a) attenuation purposes

b) stabilizing support of fragile chemical liners

c) mixing with lining materials

d) mixing with other sealants containing chemicals, lime, rubber, and plastic latexes and penetrating polymeric emulsions

Soils are effectively used for layering and the cell encasement provides another way in which migration of constituent from solid waste operations can be minimized. Infiltration can be particularly well controlled and any hydraulic connection between cells is thought to develop by lateral migration. It is not known to what degree intermixing of leachate between cells does occur.

Since synthetic liners have been used to line liquid waste storage lagoons and fluid reservoirs, they may have an application in solid waste disposal operations. They are usually made of butyl rubber, polyethylene, or polyvinyl chloride and are installed in multiple layers. The membranes must be put down carefully to avoid punctures and layers of clean soil (usually sand) must be placed on both sides of them. The synthetic materials are expensive and increasingly difficult to obtain. Unfortunately, their integrity against the effects of leachate over long periods has not been proven. Also, membrane materials are subject to rupture by heavy equipment and could be difficult to place effectively on a piece-meal basis over large areas which are now required for sanitary landfills. A research study on

synthetic liners has recently been completed by the U.S. Environmental Protection Agency.

Present day containment technology will require further development if it is to be applied with confidence and integrity in landfill design. A good starting point may include an inventory of liner systems present in the province including holding ponds, reservoirs and the like. Field testing of liners and construction techniques followed by an assessment of liner performance, leakage rates and probable reasons for failure should follow. Geophysical considerations including the compressibility and consolidation of clay, measurement of swell pressures on different clays, and liquification and diffusion of cohesionless soils which may be used in cell encasement may also deserve research attention. Investigation into the relationships of compaction versus permeability and moisture contents for optimum placement could also be considered.

3. LEACHATE COLLECTION

The use of an impermeable barrier designed for complete containment requires that some method be provided for removal of the contained fluid. The fluid in a bowl shaped liner could be pumped by a well or a series of wells or it can drain by gravity outlets in the bottom of the liner to a sump where it then must be disposed. In addition, if groundwater fluctuations are expected to interfere, a separate drainage and/or pumping system can be included to control the water table or intercept subsurface drainage. A leachate collection system should include a permeable material such as a well-graded pea gravel in combination with a slotted or perforated inert pipe to facilitate collection and flow of leachate to collection sumps.

Should the leachate enter the local goundwater system, the pattern of migration could be altered by lowering the water table at strategic points. This can be done through the use of pumping wells or by the installation of drainage tiles. Drainage tiles are preferred over wells (even though capital cost may be greater) since they avoid the problems and cost inherent in the operation of a mechanical system.

4. LEACHATE TREATMENT

Since leachate problems appear to be greatest when high levels of organic contaminants are present, the removal of organic matter becomes the top priority. Therefore, most of the effort concerning leachate treatment to date has been directed at the selection of processes which have proven successful in removing BOD, COD and possibly TOC. Unit biological processes such as the anaerobic filter, the aerated lagoon, activated sludge, the anaerobic lagoon, the fixed media unit (trickling filter and RBD) and soil treatment have received considerably more attention for leachate treatment primarily on a laboratory or pilot plant scale. Studies commissioned by our department have investigated the chemical composition of leachate.[3,28] Considering the environmental impacts of leachate constituents, the treatment procedure selected can be basically directed at whether the primary concern is to reduce the organic or the inorganic constituents.

The need for further study into the treatability, particularily biological followed by physical-chemical methods or the combination of both has been recognized in the literature. Sufficient information and understanding is available to provide for proper design, operation and control of such systems, but further research could enhance the life and

flexibility of leachate treatment units already constructed and in operation.

5. LEACHATE RECYCLE AND IRRIGATION

The concept of accelerated stabilization by collection and recycle of leachate was not developed or demonstrated until relatively recently with laboratory and pilot-scale studies.[20] The results collectively indicate that leachate recycle is a viable landfill management alternative which can make the stabilization process more predictable, allow for more rapid end-use of the site by decreasing the time for stabilization and/or leachate attenuation, and also make the concept of energy recovery through gas capture more plausible since it would be produced in greater volumes over a shorter time span. The latter consideration is justified if the gas volumes produced are sufficient to merit collection and marketing.

Recycle of leachate may be accomplished with collection facilities connected to either subsurface or surface distribution mechanisms. Subsurface recirculation would tend to avoid nuisances possibly created by open exposure of leachate to the atmosphere, although difficulty of inspection and cleaning in case of clogging may create problems. On the other hand, surface distribution would also enhance evapo-transpiration processes and thereby reduce the volume of leachate to be handled in a manner similar in concept to wastewater irrigation practices.

Very little information is available on the relative merits of surface irrigation of leachate, however, problems associated with disposal of solid wastes in high ground water area, abandoned quarries, excavations, flood plains or where moisture is intentionally added as in

the case of sewage sludge, have led to consideration of possible leachate isolation and collection for subsequent irrigation. Field studies on land application of leachate have been conducted with varying results reported on vegetative growth and soil attenuation effects. In one case no adverse effects on permanent pasture grasses or soils were noted although accumulations of calcium, magnesium, and phosphorus were detected during effluent application.[18] In another case, accumulations of iron oxides were reported on vegetation.[29] Bramble studied intermittent land application of leachate using test plots and reported that the efficiency of removal or attenuation of constituents as the leachate travelled through and across the site was a function of the application rate and frequency.[5]

SECTION V - GAS GENERATION AND CONTROL

The quantity and quality of gas released from a sanitary landfill is primarily determined by the type and extent of microbial activity and its opportunity for reaction within the landfill or surrounding environment.

In most cases, over 90% of the gas volume produced from the decomposition of solid wastes consists of methane and carbon dioxide. When methane is present in the air in concentrations between 5 - 15%, it is explosive. However, there is no oxygen in a landfill when methane concentrations in it reaches this level, so there is no danger that the fill will explode.

This property has resulted in methane being considered as both a hazardous substance and an energy source. A number of projects are presently underway in North America, in which methane gas is collected at the landfill site, is processed by upgrading its BTU content and is then released into natural gas distribution systems.

Due to its low density or to a build up of gas pressure, the methane produced within a landfill will diffuse through the relatively porous fill material. It may accumulate in explosive concentrations in sewer lines and nearby buildings. Gas from landfills has also killed nearby vegetation, presumably by excluding oxygen from the root zone.

Carbon dioxide is also produced in large quantities. It is soluble in water and reacts to a limited extent to form carbonic acid which can dissolve mineral matter, particularily carbonates in refuse, soil and rock. If this occurs, the mineral content or hardness of the water increases.

Gas migration can be controlled through the use of impermeable liners, construction of gravel trenches to intercept and vent migrating gases and installation of collector pipes, fans and venting systems.

Generation of methane gas by decomposition processes in sanitary landfills has been studied by Hertz and Stone.[5] The migration of methane into areas surrounding landfills has been described by Flower and Flower, et al.[12,13] Research at the Ohio State University in computer simulation of methane migration and migration control concluded that computer simulation constitutes a viable design tool for problems involving methane migration around sanitary landfills.[17] Computer programs were developed to solve differential equations used to describe the gas flow process. Design charts to aid engineers in predicting probable methane migration distances using site specific information were prepared. The computer programs were also extended to incorporate gas migration control facilities and to evaluate various configurations for field installations.

SECTION VI - MONITORING PLAN AND POST-CLOSURE RESPONSIBILITY

Very little attention has been given to the monitoring of sanitary landfill operations in past years. There are several reasons for this. First, landfill operations were considered to be final disposal techniques with the operation completed once the wastes were deposited, compacted, and covered. Second, not much was known about the pollution potential from leachate and gases generated from buried decomposing wastes. And finally, the amount of funds traditionally allocated to solid waste disposal activities by municipalities and industries precluded the possibility of any meaningful monitoring. The current trend is to provide some sanitary landfill monitoring but as far as legislation is concerned, no monitoring is required. Despite the fact that during the past decade some research has been done on the movement of leachate and gases from landfill sites, the state of-the-art in monitoring of landfills is rudimentary.

The extent of monitoring to be conducted and thus the cost of monitoring at any site depends primarily on the nature of the solid waste deposited and the hydrogeology of the site. Other things being equal, it is reasonable to expect that the cost of monitoring will tend to increase with the size of the operation.

A. MONITORING REQUIREMENTS

The following could be monitored: (1) Characteristics of leachate generation within the site; (2) ground-water and surface water quality in the immediate vicinity of the site and at some reasonable distance around the site; (3) characteristics of gases generated in the refuse

mass and the progression of the gases from the landfill site; (4) settlement at the site with specific attention to vertical differential settling, if necessary; (5) erosion of the cover soil from the site; (6) general characteristics and approximate quantities and location of special classifications of solid wastes deposited in the site, particularly wastes that are toxic or hazardous; and (7) the quantity and characteristics of any leachate that is collected at the site and directed to some other location, such as a sanitary sewer.

Not all of these items may be included in the monitoring program at a particular site. Factors such as topography, potential for causing environmental harm, and type of wastes handled will all have a bearing on the final plan selected. Of the items noted, ground-water and surface water quality, gas movement, and site settlement are generally of greatest importance. Another point to consider in a monitoring program is when monitoring should be done. In the event that any ground-water or surface water monitoring is anticipated, it is important that the original water quality be assessed. It is possible that certain water quality constituents such as nitrates, sulfates, alkalinity, hardness, and total dissolved solids, among others, are already present in concentrations that exceed those recommended in drinking or industrial water standards. Unless these background data are documented, it is possible that the high concentrations of these constituents may be attributed erroneously to landfill leachates.

Unless there is some reason to suspect that either methane or carbon dioxide have migrated to the site in question from some other locality (possibly another landfill site), initial background gas monitoring is normally not necessary. In the case of settlement

monitoring, it might be advisable to run a bench mark elevation circuit around and within the site to provide the necessary references for setting refuse cell elevations and for subsequent monitoring of settlement.

The biggest question is how long monitoring should be continued following completion of the landfill operation. To a large extent, each site must be evaluated individually in this regard. Such factors as the quantity of wastes deposited, the geology of the site, the depth of ground-water table, amount of precipitation, the proximity of homes or other dwellings, and the eventual use of the completed site all have some influence in arriving at a decision. In view of these variables it is difficult to provide an estimate in years, other than to state that monitoring should be continued until conditions around the site stabilize. In any case, it would not be unreasonable to expect monitoring operations to continue for a period of 5 - 10 years and even longer following the completion of the site

Another decision that must be made in the early planning stages of a landfill monitoring program concerns the amount of data that will be collected and the manner in which the data will be analyzed and interpreted. Most of the data collected will be discrete measurements at certain time intervals rather than continuous ones. Serious consideration should be given to storage of the data on computer tapes or cards to facilitate use and interpretation. If sufficient monitoring wells are available, it is helpful to summarize ground-water quality and gas data by drawing isoconcentration plots for various parameters. In this manner, the progression of ground-water "plumes" for various constituents can be easily observed with time.

B. LEACHATE AND WATER QUALITY MONITORING

To many in the solid waste field, monitoring at a landfill site means simply the monitoring of ground water in the vicinity. This is the monitoring activity employed most frequently in the past, the one that has been related to the greatest extent to past research activities, and certainly the one about which the most knowledge is currently available. The reason for this trend is not accidental since the potential for ground water pollution has always been one of the primary environmental concerns associated with the land disposal of solid wastes.

At some sites it may be advisable to monitor the characteristics of the leachate generated, although this is by no means a routine operation. Monitoring this material will not necessarily provide answers as to its potential impact on ground-water quality, but it does give an insight as to what is occurring in the refuse mass. Leachate can only be monitored in sites where the base of the refuse cell is relatively impervious either because of the geological properties of the indigenous soil or by design. In such situations, the leachate is directed toward one area in the site by proper selection of bottom slopes and develops into a pool, the extent of which depends on the soil permeability. A sampling well can be located in this general area and constructed upward as one refuse cell is deposited above another. A similar setup can be employed if the landfill site has been constructed for leachate collection and pumping. There are numerous analyses that can be run on the leachate, depending upon the intent of the monitoring program. The chemical oxygen demand will suffice if there is interest only in the rate of refuse stabilization. Other analyses that can be

run on leachate for various reasons are biochemical oxygen demand, pH, alkalinity, hardness, chloride, sulfate, sodium, potassium, calcium, magnesium, total dissolved solids, organic nitrogen, ammonia, and iron and heavy metals

Leachate may have an impact on ground-water quality only if it reaches the ground-water table. The passage of the leachate through the soil regime and the passage of the leachate-ground-water mixture through the same regime result in a marked change or attenuation in the leachate characteristics. The monitoring of ground water is akin to following the extent and progression of this attenuation mechanism around a landfill site. To accomplish this, sampling wells must be drilled up-gradient from the landfill site to obtain reference or original water characteristics and down-gradient at varying distances to establish the plumes of water quality alteration.

The decision as to what analyses should be included in a ground-water monitoring program depends on how the information is to be used. Chloride determination alone will serve as a very sensitive tracer of leachate migration. Other analyses that could be run are hardness, alkalinity, nitrates, conductivity, iron, phosphates, calcium, magnesium, sodium, potassium, sulfates and fecal coliform. Depending upon the characteristics of the solid wastes that have been deposited at the site, safety considerations may require that periodic checks be made for heavy metals and other toxic substances. The frequency of routine sampling must also be decided. While this can vary from site to site depending on the velocity of ground-water flow and proximity of water users, a reasonable sampling frequency for most sites would probably lie in the 50 - 100 day range.

An important consideration in a monitoring program is the method used for obtaining ground-water samples. Wells drilled for the purpose of site evaluation are usually not suitable for long-term ground-water sampling. These wells are drilled during the early site evaluation period, and it would be unwise to invest too much money in their construction since the decision may be made to reject the site. However, if these boring locations are judiciously slected and the drilled holes are lined with 1-1/4-in. to 1-1/2-in. (32mm to 38mm) diam plastic pipe, they can serve as temporary sampling points, at least for as long as they remain intact. The cost of obtaining water samples from such small diameter wells may preclude their use for routine monitoring; permanent larger diameter sampling wells should be drilled expressly for the purpose of routine ground-water monitoring. The well should be deep enough to ensure that ground-water samples can still be obtained with the ground-water table elevation at its estimated lowest level. Though little is known about the vertical movement of leachate constituents in an aquifer, the usual practice has been to obtain water samples just below the ground-water table. The number of sampling wells to be used in case depends on such factors as the size of the aquifer, magnitude of the landfill operation, depth to the ground-water table, permeability of the aquifer, and the proximity of the site to ground-water users. In any case, it would be difficult to envision a monitoring program without at least one sampling well up-gradient from the landfill site and possibly two or three down-gradient.

Methods of obtaining water samples and establishing elevations of the ground-water table depend upon circumstances. If the ground-water table is 7.5 m (25 ft.) or less below the surface, vacuum devices can be

used for obtaining samples. Submersible and other types of pumps can be used for greater depths, provided the diameter of the well is large enough. Otherwise bailing devices can be used, but this technique can be time consuming if the sampling well diameter is small or the depth to the ground-water table excessive. Regardless of the method used, care should be exercised in flushing the stagnant water out of the well before an actual sample is secured. Depth of flow recorders of the flat type can be used for monitoring ground-water elevations, provided the well diameter is of sufficient size. Otherwise, individual measurements can be made with chalk lines or an electrical contact device.

The possibility of using other techniques for monitoring the progression of leachate from a landfill site has been suggested, but little evidence of field experience is available. Cartwright and McCommas, Warner, and Fried have demonstrated with partial success the use of resistivity measurements for detecting and outlining zones of ground-water contamination in situations where there is a resistivity contact between contaminated and uncontaminated ground water. Montoring wells can be installed to verify the resistivity results.

At some landfill sites it may also be necessary to monitor surface waters that may be influenced by leachates. In some sites the leachate can move laterally below ground toward a gaining creek or stream (one that receives some flow from water in the zone of saturation) and results in an alteration in the water quality. Samples would have to be obtained upstream as well as downstream of the site to properly monitor this situation. At other sites in which the refuse is deposited on impervious clays and in areas of high precipitaiton, the leachate can

outcrop at the top and sides of the fill and flow with the surface runoff directly to a receiving body of water.

C. GAS SAMPLING

The most important reason for gas monitoring at a landfill site is the possibility of a hazardous situation developing within and outside of the site. Knowledge of any migration of methane from the site is particularly important because of the possible dangerous conditions that may develop in surrounding areas. Another reason for gas monitoring within the site is simply the obtaining of data on the progress of organic waste decomposition. As this fraction becomes progressively stabilized, gas production will decline.

A gas monitoring program is more difficult to establish than a water quality monitoring program because of the difficulty of predicting where the gas will migrate. If the cover material has a high clay content, is well compacted, or is wet or frozen, it is not too likely that the gas will diffuse uniformly up through the cover. Rather, it will tend to move laterally until some outlet occurs. Some sites are designed with gas barriers and gas channeling devices to ensure that the gas is released at certain preselected points, sometimes through vertical vents designed for this purpose. Regardless of the landfill design, it is essential that some effort be made to predict the general migration pattern of the gas and to establish the gas monitoring program on the basis of this background information. Plots of isoconcentration lines of field monitorial gas concentrations may assist in determining migration patterns. Care should be taken in obtaining a representative sample for gas analysis both within and around the site. Possibilities

range from a simple "dry well" to inverted gas-capturing devices. A number of different techniques may have to be tried at each site before a suitable arrangement is achieved.

Though not routinely used for analysis of landfill gases, the most accurate instrument for the purpose is a gas chromatograph. This is a delicate instrument, and the analysis should be conducted in the laboratory. Portable gas meters (often called explosion meters) are most commonly used for in situ gas analysis. It is necessary to take gas samples from within the fill rather than from the air above the soil cover. A further caution in the use of portable units is that they should be calibrated frequently against a more precise instrument such as a gas chromatograph; otherwise, the results may be very misleading.

D. OTHER POSSIBLE MONITORING

Besides serving as another indicator of degradation activity, there are some other useful purposes served in monitoring settlement. Knowledge of settlement is useful in planning future uses of the site and in planning for future earth-moving equipment and labor requirements necessary to maintain established grades. There is no totally acceptable technique for monitoring settlement at a landfill site. At some sites, surface "settlement plates" have been employed. These are usually steel or concrete squares, with sides approximately (0.6 m) 2 ft long. For more precise surface settlement monitoring, concrete or stone monuments of the type used as bench marks in surveying should be used. Regardless of the devices used, it would be good practice to establish a reasonable network of permanent bench marks around the site to minimize

the cost of obtaining the elevations needed during the monitoring program.

Consideration might be given to monitoring the rate of cover soil erosion. The eventual use of the site will determine to a large extent whether this is a matter of real interest. Completed sanitary landfill sites have been used for agricultural purposes, in which case erosion rate is of vital concern. At sites where sods or other vegetal covers are used, erosion is of minor concern. The actual amounts of erosion will depend on the type and compaction of soil cover as well as the type and extent of vegetation. Monitoring of this type is primarily visual, in which the observer checks the completed portion of the sites for gully formation and exposed solid wastes.

In most sites, and especially in sites where loads of industrial wastes are admitted for disposal, it would be a good practice to monitor the general types of material being brought to the site. If problems do develop in the future, it would then be possible to consult the operating logs and establish the location of specific wastes within the site and the date on which they were deposited. These data could be kept by the personnel in charge of the weighing station at larger sites, or by the equipment operators at smaller sites. Personnel responsible for this task should be properly trained to make qualitative and quantitative estimates, particularly if more than one person is involved. Past experience has shown that assigning tasks of this nature to poorly trained or uninterested personnel could lead to highly erroneous results.

If, in a landfill operation, there is interest in monitoring the rate of organic matter stabilization, consideration might be given to

measuring the temperature of the decomposing refuse mass. Temperature data, together with the data on gas generation, leachate production, and settlement, provide fairly complete monitoring of degradation.

Finally, since sites are designed to accept a specific amount of solid wastes, periodic monitoring of in-place density at the site will provide a valuable operating tool. Weight data from scales or other means, in addition to field survey information, are necessary to make this calculation

E. MONITORING RESPONSIBLITY AND CORRECTIVE ACTIONS

Probably one of the major problems in a landfill monitoring program is the assignment of responsiblity for this activity. If a municipality or other governmental entity owns and operates the site, the problem is somewhat simplified in that the regulatory or licensing agency may simply require that monitoring of the site be conducted during operation of the site and for a number of years into the future.

The problem becomes somewhat more complex if the site is privately owned. In some cases, the operator contracts with the land owner for use of the site for landfilling. In this situation, the licensing agency could require monitoring of the site while it is in operation. Upon completion of the operation, exercising control on this activity becomes much more difficult, unless the requirement for posting a performance bond or some other guarantee is made. A precedent has certainly been set in the case of other public works projects such as water and wastewater treatment plants, pumping stations, and storm water tunnels. In any case, it would appear essential that the monitoring program be worked out in close cooperation with the regulatory agency.

In the U.S., the Environmental Protection Agency has begun to come to grips with these issues. The State of Wisconsin has introduced legislation that would provide for perpetual care of disposal sites. In the Wisconsin case, long-term care is defined as:

> "The routine care, maintenance, and monitoring of a solid waste or hazardous waste treatment, storage, or disposal facility following closing of the facility."

Routine long-term care is to include:

a) monitoring-gas, soils, water quality

b) land-surface care-drainage, erosion, settlement

c) leachate management

d) gas control

Any approved engineering design for a facility must include provisions for long-term care and the operator is required to provide a bond, deposit or other proof of financial ability to comply with the closure and long-term plan.

The owner is responsible for long-term care for 30 years following site closure. After 30 years, costs of additional long-term care, if needed, are to be financed by a "waste management fund". The fund is established by charging a user fee over the years that sites accept wastes. In the case of Wisconsin, all facilities in the state, whether approved or not, would collect the user fee and deposit it into the state run fund to achieve a reserve of $10 million.

Only sites licensed and approved by the state may withdraw money from the fund. Payout would be based on an "unanticipated environmental occurence" and would not apply in cases of negligence.

The question of how and when corrective action should be taken once the monitoring program results indicate that troublesome or hazardous situations have developed is even more complex. The fact that the potential problems usually occur underground adds to the difficulty of applying any corrective actions. In regard to ground-water quality alterations, the main question is "At what point must corrective actions be taken?" Should governmental drinking water standards or other standards be used as a reference? In some cases, original water quality does not meet the recommendations appearing in these standards, particularily in the case of dissolved solids, iron and nitrates. The main reason for monitoring ground-water quality is to ensure that users of this water in no way suffer from some alteration in the quality. If, for example, the travel of the chloride plume from a landfill site indicates that users may be affected, measures can be taken to monitor the wells of the individual users. If quality deterioration continues, it would be the responsiblity of the landfill operator and owner to provide another source of water or to make other restitution to the water users. In extreme cases it may be necessary to intercept or isolate the contaminated ground water. Note, however, that with proper site selection and operation, the possibility of arriving at this situation is very slight.

Corrective measures, if necessary, can usually be applied more readily in the case of surface water quality alterations. It is usually possible to intercept the path of surface leachate travel with some type of drain tile collection system and to pump the leachate to some other location for treatment or for deposition in a more suitable environment.

It may be more difficult to correct gas problems because of the devious ways in which gas can travel. The principal reason for monitoring methane or carbon dioxide is to have some knowledge of where the gas goes. If methane becomes a problem, it is possible to institute certain remedial measures. Excavations can be made within or around the periphery of the site for the installation of gas barriers or venting systems where needed. It is also possible to install a positive venting system if deemed necessary. If the methane is migrating from the site to surrounding areas and could constitute a hazard, it would become the responsibility of the landfill operator and the owner to expand the monitoring program into these areas and to take the steps required to alleviate the hazardous situation. As in the case of ground-water quality monitoring, only the posting of a performance bond in some instances will ensure that this follow-up activity will take place.

Arguments have been made that requirements for performance bonds and trust funds are unnecessary because it should be possible to provide insurance coverage for such occurences. However, insurance companies are most reluctant to provide coverage because it is difficult to predict the type and frequency of such events. Fortunately, one might say, such events have happened so seldom that recorded statistics are not reliable as data upon which to make predictions. There appears to be some merit in keeping it that way.

SECTION VII- FINAL LAND USE PLAN

Completed sanitary landfills are typically either returned to agriculture, developed as recreational areas or developed for residential or industrial building construction.

Before a decision is reached on the final land use, the settlement and structural characteristics of the landfill must be considered as well as the production of toxic or flammable gases. It has been found in various studies that about 90% of the ultimate settlment occurs within the first five years. The placement of concentrated loads on completed landfills is not recommended unless piles extending into undisturbed material are used. All services to the structure must also be founded on piles.

Studies conducted by a number of investigators have indicated that early stabilization of a landfill can be achieved by placing the landfill material at as high an initial density as possible or by preloading the site with surcharge for some time prior to construction.[1] Injection grouting using other solid waste products like fly ash to fill the voids of sanitary landfills has been suggested as an alternate early stabilization technique. The design and resulting performance of any structure built on a landfill will depend to a great extent, upon the ability to predict the rate and magnitude of the anticipated settlement. Presently this is very difficult because of the large deformations involved and the scarcity of reliable data upon which to base settlement theories. The former problem can be treated through appropriate consideration of the factors involved. The latter problem can only be overcome through field and laboratory research, including careful long

term settlement observations. Some progress along these lines has been made in recent years, but much more needs to be done before appropriate theories can be formulated and validated.

As indicated previously, both hydrogen sulfide and methane gases are produced in sanitary landfills. Hydrogen sulfide gas is toxic to humans and may be fatal if present in high enough concentrations. Methane gas presents an explosion or fire hazard if landfill gas was to migrate into building structure. As a result of this hazard, buildings placed on completed sanitary landfills must be designed to prevent entry of landfill gas. Permanant monitors and exhaust systems within the buildings would be necessary to detect the presence of methane gas and to remove it from the building should entry occur. In 1979, an investigation was conducted by our department to determine the source of combustible gases entering a structure built on the reclaimed Beverly sanitary landfill.[16] A detection and ventilation system is used in the structure.

In order to eliminate the hazard associated with settlment and the presence of toxic or flammable landfill gas, buildings should not be placed on completed sanitary landfills unless absolutely necessary. A more logical use of completed landfills would therefore be a return to agriculture or development of recreational areas. The potential exists for damage to grass and trees and this factor must be considered during the application of final cover material.

SECTION VIII - OPERATIONS MANAGEMENT

Management of a sanitary landfill involves a wide range of responsibilities and a number of specialties. The management has fiscal responsibilities (cost accounting, bookkeeping, budgets), social responsibilities (labor, hiring, training, safety and health, public relations) and operational responsibilities (equipment maintenance and replacement, site engineering, final use, security, etc.). Continuity of management over the life of the site is desirable, and a site should be managed, in an engineering sense, from the "cradle to the grave".

The landfill is operated by the municipality or waste management authority or the operation may be contracted out. A combination of the two where only certain operations such as trench excavation, daily covering, and debris clean-up, etc. are contracted out may also exist.

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